

Chapter 8 Anchoring Structures

8-1. General

Structural anchors are often used to improve the stability of existing structures but, generally, should not be used as a primary means to stabilize new, large mass concrete structures. If a situation exists where anchors are used to stabilize a new structure (space limitations and/or economics dictate their use), prior approval from CECW-E must be obtained. This chapter provides guidance on the design of anchoring structures to rock, it does not include information on soil anchors. Use of soil anchors for permanent structures is not allowed without prior approval from CECW-E. Untensioned structural anchors are commonly used in designs of new structures to stabilize thin concrete members on or against competent rock. Thin concrete members include walls, chute slabs, stilling basin slabs, and paved channel slabs. For such uses, prior approval from CECW-E is not required. Following are brief descriptions of new projects which did utilize anchors into rock to stabilize large structures.

a. Bay Springs Lock. This lock was located in a deep-rock excavation so a considerable savings was achieved by anchoring the lock walls to the rock. This reduced the amount of rock excavation and the amount of mass concrete. This project was designed by the Nashville District.

b. Bonneville Lock. This lock and the upstream approach channel wall are in close proximity to a railroad. So, to avoid relocating the railroad it was determined the most economical design was to use structural anchors to stabilize the walls. This project was designed by the Portland District.

c. Wanapum Dam. Tensioned structural anchors have also been used by others to stabilize new structures. The Wanapum project included a hydropower station designed to provide for six future generating units. To reduce initial costs, only the intakes for these six future generating units were constructed. Since the entire structure was not built, the intakes lacked stability. The most practical and economical solution was to use tensioned structural anchors to stabilize the monoliths (Eberhardt and Veltrop 1965).

8-2. Anchoring Structures to Rock

a. Tensioned structural anchors. Inclined, tensioned structural anchors are effective in increasing the stability of structures by improving factors of safety against sliding and uplift, and improving the resultant location. The number, orientation, and capacity of anchors should be based on engineering considerations and stability requirements. The process of installing tensioned anchors consists of:

- drilling holes across the potential failure plane to accommodate anchor installation
- installing the anchors
- grouting the fixed or dead end of the anchors
- jacking at the stressing or live end of the anchor to induce an active tensile force which will provide a clamping action across the potential failure plane
- grouting the remaining ungrouted length of the anchor for corrosion protection.

Fixed end anchorage is created by grouting the annular space around the tendons for a length of tendons (bond length) sufficient to develop the ultimate tensile capacity of the anchorage system. Full active tensile load is developed in the remaining ungrouted (free stressing length) of the tendon anchor system by jacking at the free end of the tendons. The tensile force induced in the free stressing length of the anchor loads the potential failure plane with a compressive stress normal to the failure plane and for inclined anchors, a horizontal component that counteracts applied shearing loads. Allowances are made in the jacking load for anticipated losses such as relaxation of the tendons, seating losses, creep, and foundation consolidation.

b. Anchor System Selection. There are a large number of products and systems to choose from, with the primary considerations being cost and corrosion protection. Generally, fewer higher capacity anchors are less expensive than more smaller capacity anchors, however with high capacity anchors, the failure of a single anchor can result in a significant loss of sliding resistance along the potential failure plane. Single, high-strength steel bars

have the smallest capacity of tensioned anchors, while steel strand is used when large capacity anchors are needed. Single bars provide less force because they have a lower working stress than strands. The three most common types of anchor systems are the hollow groutable anchors, the solid continuously threaded bar anchors, and strand anchors. Following is a brief description of each system.

(1) The hollow-groutable anchor system consists of a threaded high-strength reinforcing bar with a hole in the middle to permit the annular space around the bar to be grouted after tensioning is complete. Anchorage of the dead end is accomplished by an anchor cone, which engages the existing concrete. The bar is tensioned by hydraulic jack, or by tightening the nut located at the stressing end of the unit.

(2) The threaded-bar anchor system is tensioned with a center pull jack. A special threaded nut is used for locking- in the applied tension. The threaded bars may be secured in two-stage cement grout or fast- and slow-set polyester resin grouts. Long-term creep of polyester resin has been a concern that stems from laboratory tests at high-bond stresses. Generally, creep at normal working-level stresses will not be a problem.

(3) The strand anchor system is a seven-wire type having a center wire wrapped tightly by six outer wires. Strand anchors use single- or two-stage grouting with the single-stage grouting being referred to as an unbonded anchor, while the two-stage grouting procedure is referred to as a bonded anchor. The free stressing length of bonded anchors are grouted after the anchor has been stressed.

c. Untensioned structural anchors. Untensioned anchors shall not be used to improve sliding stability or resultant location since they may require excessive displacement before becoming effective. However, untensioned structural anchors may be used for the following situations.

(1) Walls. Anchored walls should be considered in areas where the rock is strong and firmly in place but is subject to surface expansion and exfoliation upon exposure. The concrete wall acts as a lining, which serves to limit the surface deterioration and to protect it against erosion from flowing water. The lining should be anchored adequately by untensioned structural anchors grouted into drilled holes in the rock. Unless the rock mass is essentially free of jointing, the anchorage should extend deep enough to engage a sufficient mass of rock for stability with a factor of safety where the anchored portion is assumed to be separated from the adjacent rock by continuous cracks. In some cases, the existence of definite slip planes dipping into the channel may require deeper anchorage near the top of the wall. Anchors may be installed at any inclination, except inclinations less than 5 degrees from horizontal, which should be avoided due to difficulties with installation. Horizontal and upwards-sloping anchors require specialized grouting techniques. Drainage should be provided to reduce the hydrostatic pressure behind the wall as much as practicable. Drain holes drilled into rock with outlets through the concrete generally provide the best and simplest system. The drain holes are sloped down a little toward the outlet and should be deep enough to adequately drain those cracks within that rock mass necessary for stability, plus the area immediately behind the mass. In cold climates, concrete thickness required for frost protection of poor rock may determine the wall thickness. Otherwise, the anchorage and concrete lining are designed to withstand the reduced hydrostatic pressure.

(2) Slabs. Anchored slabs on rock are designed to withstand uplift and other probable forces with an ample factor of safety. If the slab is on suitable rock, the slab can be anchored with untensioned structural anchors grouted in holes drilled into the rock. The holes shall have a sufficient depth to engage a mass of rock the submerged weight of which will withstand the net upward forces, assuming the mass of rock bounded by a 90-deg apex angle at the bottom with allowance for overlap from adjacent anchors. Drain holes drilled into the rock and discharging through the slab can reduce unbalanced hydrostatic uplift. Depth and spacing of drain holes should be determined by consultation with the geotechnical engineer. The holes should be inclined at a small angle from normal to the slab so that their outlet end is downstream from their inlet end to avoid a possible increased uplift from flowing water. A pervious drainage blanket under the slab with transverse perforated drain pipes discharging through the slab may be economical where a blanket is needed to protect the foundation from freezing.

8-3. Tensioned Anchor Loads

For inclined structural anchors, the normal component of the anchor force adds to the frictional resistance by increasing the normal force on the sliding plane, and the tangential component acts against the driving forces as

resisting forces. The horizontal component should be treated as an applied load (see example D5 in Appendix D). Adding the horizontal component to the frictional resistance is not logical since the frictional resistance is a function of the normal loading and angle of internal friction, while the tangential component is related only to tendon load and inclination of the tendon. These applied loads occur immediately upon stressing the anchors and are not associated with deformations accompanying the development of frictional resistance. Thus, it should be considered an applied load that induces shear stresses along potential sliding planes opposite in direction to those due to downstream forces on the structure.

Rehabilitation of existing structures should examine a range of anchor forces varying from the force needed to meet Chapter 3 stability requirements to minimal forces needed to meet the requirements discussed in Chapter 6. A check should be made to ensure that the tangential component is never so large as to cause upstream sliding. An example might be that the tangential component applied to a dam is equal to or larger than the reservoir load on a dam. This raises the question of possible upstream sliding should the reservoir ever be evacuated.

8-4. Structural Anchor Design

a. Tensioned structural anchors. Recommendations for Prestressed Rock and Soil Anchors (Post-Tensioning Institute 1996) provides guidance in the application of permanent and temporary utilizing high-strength prestressing steel (includes bars and strand guidance). The recommendations do not deal with the design of anchored structures in general, but are limited to considerations specific to the prestressed anchors. Design, materials, fabrication and handling, installation, and performance testing of permanent tensioned structural anchors should be in accordance with PTI 1996 subject to the following provisions.

- PTI Chapter 3.0, “Specifications and Responsibilities” is not applicable because the structural anchors are a part of a larger Corps project and, as such, the structural anchors are included as a part of the contract documents.
- PTI Chapter 4.0, “Materials” requirements shall be used for prestressing steel (strand, bar, indented strand, epoxy-coated strand, epoxy-coated bar), anchorages, couplers, centralizers and spacers, corrosion inhibiting compound, bond breaker, sheath, tendon bond-length encapsulations, heat-shrinkable sleeves, grout tubes, anchor grout, cement grout, and polyester resin grouts.
- PTI Chapter 5.0, “Corrosion Protection,” provides guidance for two classes of corrosion protection. Class I, encapsulated tendons, is often referred to as double corrosion protection while Class II, grout protected tendons, is often referred to as single corrosion protection. Class I corrosion protection shall be used for the anchors.
- PTI Paragraph 6.4.2 discusses fully bonded and unbonded anchors. Fully bonded anchors are required and shall be grouted in two stages, i.e., first stage (primary) is to grout the bond zone, and the second stage is to grout the free length after the anchor has been stressed.
- PTI Paragraph 7.4 discusses waterproofing rock-anchor drill holes. Provisions in this paragraph are a requirement.

b. Untensioned structural anchors. There is no industry standard for the design of untensioned structural anchors. Such anchors shall be ASTM grade 60 bars designed in accordance with EM 1110-2-2104. Anchors are usually of large diameter to reduce drilling cost. With large anchors however, the strain penetration that occurs in the reinforcement on each side of the failure plane is large, requiring significant elongation to develop the ultimate capacity of the anchor.

c. Bond length for tensioned and untensioned structural anchors. The required anchorage length is based upon tendon load, diameter of the tendon hole, type of tendon system, and the bond strength between the surrounding material and grout and between the tendon and grout. The bond lengths calculated below should be verified by performing pull-out tests utilizing tendon systems and drill-hole sizes matching those used by the contractor. If the foundation is variable, pull-out tests should be performed in areas representative of all site conditions and bond lengths adjusted accordingly. The embedment, and/or hooks, in the concrete for untensioned structural anchors should be in accordance with the requirements of EM 1110-2-2104. Embedment length should not be confused with the anchorage bond length of the tendon. Bond lengths for tensioned and untensioned

structural anchors can be determined by using the largest value resulting from the computations in paragraphs (1), (2), or (3) below.

(1) Bond between tendon and grout

$$L = P / (\phi \pi d_b f_{bu})$$

where: L = bond length

P = ultimate load for untensioned anchors and design load for tensioned anchors

d_b = diameter of tendon

f_{bu} = ultimate bond strength between tendon and grout (For design, use f_{bu} equal to $6\sqrt{f_c}$, where f_c is the compressive strength of grout; f_{bu} must be verified by tests as specified in PTI 1996)

ϕ = strength reduction factor = 0.9 (Not to be confused with soil strength parameter.)

(2) Bond between grout and rock

$$L = P / (\phi \pi d_h f_{cu})$$

Where: d_h = diameter of drilled hole

f_{cu} = ultimate bond strength between grout and rock, or c , whichever is less (see Table 6.1 of PTI 1996 for values of f_{cu})

c = cross bed shear value in rock in the direction of pull out

(3) Rock-mass shear failure

(a) Tensioned structural anchors. With all tensioned structural-anchor systems, a major consideration is determining how deep to install the anchors. An anchor system that is too shallow may cause tension and cracking to occur along potential failure planes in the foundation, and a system too deep is uneconomical. PTI recommends normal bond length not less than 3.0m (10ft) for bars and 4.5m (15ft) for strand. Bond lengths greater than 10m (35ft) are normally not used. PTI recommends free stressing lengths to be at least 3.0m (10ft) for bar tendons and 4.5m (15ft) for strand tendons. Center-to-center spacings between anchors shall be at least 1.5m (5ft) unless unusual circumstances dictate. The fixed end (dead end) anchorages should be staggered.

(b) Untensioned structural anchors. For untensioned structural anchors, rock-mass failure will not normally govern design. Where the foundation consists of weak or cracked rock, a rational analysis should be performed to ensure adequate embedment length. This analysis should be performed in accordance with the requirements given in EM 1110-2-2400.

d. *Anchorage for tensioned structural anchors.* Anchorages shall be a combination of either a steel bearing plate and wedges, or a steel-bearing plate with a threaded anchor nut. The anchorage components must be carefully designed, detailed and constructed to provide adequate corrosion protection. It is also important to properly detail the region under the anchorage. Large tendons will exert very large forces on the bearing plate, which will then be distributed into the concrete. This will result in localized stress concentrations in the concrete at the edges and/or immediately beneath the bearing plate. Anchor details and bearing plate requirements are available from the post-tensioning system manufacturer. Guide specifications for post-tensioning materials are available from the Post Tensioning Institute (PTI), and contain information on permissible compressive concrete stresses beneath stressing-end anchor plates.

8-5. Stressing, Load Testing, and Acceptance

Field tests shall be performed before and during the installation to verify the adequacy of the anchor system and installation procedures. Tests before installation shall be used to check the performance of selected drilling method, conformability of hole size and drift tolerances, adequacy of assumed bond strengths between grout and rock, grout and concrete, and grout and tendon. Tests during installation should be adequate to ensure that anchors are installed in accordance with the requirements of the plans and specifications and that the ultimate capacity of the tendon can be developed. The number of tests required depends on the site-specific information including drilling conditions, type and/or size of tendons, and complexity of foundation formation and material. All testing procedures and acceptance criteria shall be in accordance with PTI 1996.

8-6. Monitoring Structural Anchor Performance

Grouting, which is required to protect tensioned anchors against corrosion, results in a fully bonded anchor. Untensioned anchors are installed with a single grouting process which also results in a fully bonded anchor. Therefore, the long-term monitoring of anchor systems is limited. It is assumed that fully bonded anchors are maintenance free because the alkalis in the grout provide extra corrosion protection, the entire anchor is not lost if a portion of the anchor fails, and small, localized movements can mobilize reserve capacity in the anchor. Inspection of the structure and monitoring of its behavior are the only practical ways of monitoring performance of fully bonded, structural anchors. Provisions are being developed that will allow measurements of galvanic action within the anchor system. Also, sensors can now be embedded in fiber-optic cables. These cables have been epoxied to ship hulls, bridge girders and reinforcing bars with the sensors transmitting data in real time. It is believed they could be epoxied to anchors. These procedures may be investigated by the designers if there is a need for further assurance that an anchor system remains functional.

8-7 Mandatory Requirements

- a.* It is mandatory to obtain approval from CECW-E prior to use of soil anchors to meet requirements for stability of permanent structures.
- b.* It is mandatory to obtain approval from CECW-E prior to use of rock anchors to meet requirements for stability of new mass concrete structures.